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Ventilation Rates and Health

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While ventilation rates do not directly affect occupant health or perception outcomes, they affect indoor environmental conditions including air pollutant concentrations that may modify the occupants' health or perceptions. This article summarizes the review by Seppänen, et al. of current literature on the relationship of ventilation rates and carbon dioxide concentrations in non-residential and non-industrial buildings (primarily offices) with the health of the building's occupants and with the occupants' perceptions of indoor air quality (IAQ). The review aims to provide a better scientific basis for setting health-related ventilation standards. This summary focuses primarily on the ventilation rate studies.

The review considered three human responses due to their widespread occurrence and potentially great economic impact: communicable respiratory illnesses such as common colds and influenza; sick building syndrome (SBS) symptoms such as eye, nose and throat irritation, headache, tight chest, and wheeze, which decrease when the individual leaves the building; and perceived unacceptability or poor quality of air.

The review included almost 30,000 subjects in 20 ventilation rate studies, and more than 350 buildings. Most studies included office workers, but some studies were performed with special groups including army trainees, elderly nursing home residents, jail inmates, pupils in schools, and hospital personnel.

Two types of field studies were included in the review. In cross-sectional studies, data on health (or perceived IAQ) outcomes, ventilation rates, and other relevant factors that may influence health or perceived IAQ were collected

from multiple buildings or building spaces and analyzed with statistical models. A major weakness of this study design is that many factors other than ventilation rates, which vary among buildings, may influence health outcomes, confounding the association of ventilation rate with health outcome.

The criteria for including cross-sectional studies in the review were: at least three buildings or ventilation zones, statistical analysis of results, and control in the statistical analyses for confounding by personal factors such as gender. Many of these studies also controlled for potential confounding by some job, building, and indoor environmental factors.

The second major type of study is an experimental or intervention study. In one or more buildings or spaces, the ventilation rate was set sequentially at two or more values and the health outcomes were recorded at each ventilation rate. Much of the potential confounding was eliminated with this type of study. For example,

personal, job, and most building characteristics are unchanged when ventilation rates are modified. Some residual confounding can occur due to parameters that may change which may vary among the experimental periods, such as indoor temperature. The review included only experimental studies that met study quality criteria, as described in the original paper.

As a primary indicator of the magnitude of ventilation rate, this review used outdoor airflow rate per person (cfm per person). This was the most commonly reported ventilation rate metric in the reviewed studies, and the metric often used in codes and standards. In many studies, only the rate of mechanical outside air supply was measured, thus, the measurements did not account for additional ventilation caused by air infiltration.

Many studies assessed the association of ventilation rates with multiple health or perception outcomes (e.g., influenza and total respiratory illness) or performed multiple analyses using different categories of ventilation rates or different subsets of study data. Consequently, many studies provided multiple "assessments" of the associations of ventilation rates with human outcomes. Therefore, in the subsequent discussion we often refer to assessments.

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Studies used statistical models to quantify the strength and statistical significance of the associations between ventilation rates and health outcomes. As a measure of strength of associations, we use the percentage change in the prevalence of the health outcome estimated from results presented within the original papers. When we use the term “statistically significant,” it means that a less than 5% probability exists that the reported association between ventilation rate and a health outcome is the result of chance.

Results

Communicable respiratory illnesses and ventilation rates. Only three studies of communicable respiratory illnesses were included in the review. These studies took place in a military barracks, a nursing home, and a jail. All found a statistically significant increase in the prevalence of illness in the group with a lower ventilation rate. The percentage increases in respiratory illness with a lower ventilation rate varied between 50% and 120%, with one outlier of 370%. A fourth study within a set of office buildings found a statistically significant 53% increase in short-term absence with lower ventilation rates. Short-term absence may be a surrogate for communicable respiratory illness.

SBS symptoms and ventilation rates. Twenty of 27 assessments found a statistically significant increase in the prevalence of one or more types of SBS symptoms as ventilation rates decreased. Sixteen of these assessments found a statistically significant increase in the prevalence of more than half of the reported types of SBS symptoms. The results of several studies suggested that the risk of SBS symptoms continues to decrease as ventilation rates increase above 20 cfm (9 L/s) per person, the minimum rate for offices in ANSI/ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*. However, the benefits of increasing ventilation rates above 20 cfm (9 L/s) per person were less consistent than the benefits of increasing ventilation rates up to 20 cfm (9 L/s) per person.

The percentage increase in SBS symptoms with lower ventilation rates varied widely. In nine assessments, the prevalence of at least one symptom increased by more than 80%. The results of one of the largest studies implies that, on average, a 10 cfm (5 L/s) per person increase in ventilation rate would reduce the prevalence of the most common SBS symptoms by more than one-third.

Three assessments found a significant increase in the prevalence of SBS symptoms with increases in ventilation rate. Each of these studies took place during winter in a cold dry climate. We hypothesize that the very low indoor humidity that occurs with high ventilation rates in such climates may have caused the increase in symptoms.

Perceived IAQ and ventilation rates. Seven of eight studies found a statistically significant worsening in perceived IAQ as ventilation rates decreased, while one study had the opposite finding.

Carbon dioxide studies. The review included 21 carbon dioxide concentration studies involving more than 30,000 subjects in more than 400 buildings. More than half of the assessments found that a higher CO₂ concentration was significantly associated with a worsening of at least one outcome, generally SBS symptom prevalence or perceived air quality. As such, the results of the studies on the association of CO₂ concentrations with health and perceived IAQ outcomes support the findings of an association of ventilation rates with outcomes.

Outcome	Number of Studies or Assessments	Number Finding Statistically Worsening (Improving) Outcome at Lower Ventilation Rates	Increase in Outcome at Lower (Higher) Ventilation Rates
Communicable Respiratory Illness or Short-Term Absence	4	4 (0)	51%; 53%; 94%; 120% to 370% (n/a)
SBS Symptoms	27	20 (3)	Usually 10% to 100%; >80% in 9 assessments (54% to 420%)
Perceived Less Satisfactory IAQ	8	7 (1)	60% to 180% (53%)

Table 1: Summary of major findings of human outcomes in reviewed studies.

Discussion and Limitations

This review provides persuasive evidence that health and perceived air quality will usually improve with increased outside air ventilation. The full paper examines several potential sources of bias, but identified none likely to explain the overall findings. Nevertheless, there are several important limitations in the current data and associated knowledge. Most studies were performed in Europe and most were in office buildings. Few studies have been performed in hot, humid climates. Relatively few studies of communicable respiratory illness have been reported. The benefits of increasing ventilation rates above 20 cfm (9 L/s) per person are less certain than the benefits of increasing ventilation rates up to 20 cfm (9 L/s) per occupant. Existing data do not indicate whether outside air supply per person or per unit floor area is more strongly associated with health and perceived IAQ. Finally, the reasons for improved health and perceived air quality with increased ventilation are uncertain.

Practical Implications

The available data indicate that occupant health and perceived IAQ will usually be improved by avoiding ventilation rates below 20 cfm (9 L/s) per occupant and indicate that further improvements in health and perceived IAQ will sometimes result from higher ventilation rates up to 40 cfm (18

L/s) per person. These findings are relatively consistent for office buildings located in cold or moderate climates, but less certain for other building types and climates.

The limitations in the existing data point to several research needs. Some of the pressing needs include research on the benefits of increasing ventilation rates above 20 cfm per occupant, research involving schools and retail buildings, and research within hot, humid climates. Because increases in ventilation may increase building energy consumption, research is also needed to identify practical methods of decreasing minimum ventilation requirements by reducing indoor pollutant emissions or by increasing the effectiveness of ventilation in controlling pollutant exposures.

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Bibliography

Seppänen O.A., W.J. Fisk, M.J. Mendell. 1999. "Association of ventilation rates and CO₂-concentrations with health and other responses in commercial and institutional buildings." *International Journal of Indoor Air Quality and Climate* pp. 252-274. ●